9.0 Summary of Results and Discussion

Given that electric power production from biomass has considerable potential to contribute to energy supplies in the United States, it's important to assess the environmental consequences up-front, while system components are still being defined. By analyzing the emissions, resource consumption, and energy use of the entire system, including biomass production, transportation, and electricity generation, the dominant sources of environmental impacts can be determined and the resulting effects can be reduced. For these reasons, a life cycle assessment of a biomass power plant, including all upstream production and downstream disposal processes, was conducted.

General trends can be seen when examining the resources, emissions, and energy over the life of the biomass-to-electricity system described in this report. In years preceding power plant construction and operation, all of the stressors are associated with feedstock production, and as expected, there is a yearly increase as the number of fields in production is increased. A majority of the stressors are highest in the two years before plant operation due to activities associated with plant construction. The impacts then tend to be level during plant operation even with the construction and decommissioning activities associated with the farm equipment and truck transportation. Finally, a gradual decrease is seen, starting in year 23 when biomass production tapers off, leading up to a rapid decrease in impacts during final decommissioning.

Of all air emissions from the system, CO_2 is emitted in the greatest quantity. Feedstock production, primarily the use of fossil fuels in farming operations, is responsible for greater than half of all net CO_2 emissions. Other emissions commonly described as greenhouse gases, specifically methane and nitrous oxide, are emitted in very small quantities and add a minimal amount to the global warming potential of this system.

Because carbon dioxide emitted from the power plant is recycled back to the biomass as it grows, biomass power systems have the ability to reduce the overall amount of CO_2 added to the atmosphere. The system studied was found to have a 95% carbon closure, with 100% representing total recycle, i.e., no net addition of CO_2 to the atmosphere. The amount of carbon that is sequestered by the soil at the plantation most strongly affects the carbon closure of the system. If the range of literature values for soil carbon sequestration is applied, carbon closure may be as low as 83% or as high as 200% (i.e., a net reduction in the amount of atmospheric CO_2). Conducting sensitivity analyses on other assumptions used in this study predicts carbon closures greater than 94%.

The base case analysis assumed that there would be no net accumulation or loss in soil carbon, with a sensitivity analysis showing that if 1.9 Mg/ha over the seven year crop rotation could be sequestered, the carbon cycle could be closed. In other words the system would be a zero-net CO_2 process. Literature values for soil carbon build-up ranged from a loss of 4.5 to a gain of 40.3 Mg/ha/seven years.

Isoprene, the compound used to model biogenic emissions from the trees, is released to the air in the second highest amount. However, its impact on the environment cannot be directly assessed from this result without further study. NOx and NMHCs are the next highest emitted, followed by SOx. NOx, SOx, and particulates are released from the power plant at rates one-fifth, one-tenth, and 1/28th of those required by the New Source Performance Standards (NSPS) for fossil-fueled plants. Particulate emissions, although not found to be released in significant quantities overall, are greater than six times higher during the two years of plant construction than during normal operation. NMHC emissions, primarily from operating the power plant, represent only 0.9% of all air emissions. The majority of air emissions produced in the feedstock production section are typical of those from diesel-fueled farm equipment. However, the total amount of these emissions is small in comparison to air emissions from the power plant.

A previous technical and economic analysis on this system was revisited in the context of this life cycle assessment. To reduce the emissions of VOCs from the power plant, a slipstream of the dryer exhaust gas is recycled to the char combustor. This configuration is a change from the original design and technoeconomic analysis given in Craig and Mann (1996). The cost of an additional blower and its electricity consumption result in a minimal increase in the selling price of electricity to 6.75 ¢/kWh in current dollars or 5.25 ¢/kWh in constant dollars.

Emissions to water occurred mostly in the feedstock production system since the power plant treats a significant quantity of its water prior to discharge. It's important to note, however, that the total amount of water pollutants was found to be small compared to other emissions. In addition to the air and water emissions, non-hazardous solid waste was produced, but in small quantities.

Water is the resource consumed in the largest quantity by this system. Because rainfall was assumed to be adequate for water requirements at the plantation, water is consumed only in upstream manufacturing operations, and especially by the power plant itself. Excluding water, oil, iron, and coal account for 95% by weight of the other resources consumed. As expected, the majority of fossil fuels are consumed by farming operations in feedstock production. By weight of substance, the percentage of the total consumption of natural gas, oil, and coal used in the feedstock subsystem equals 95%, 79%, and 67%, respectively. Because of equipment construction, the power plant was found to require more electricity, and thus more coal and natural gas, than biomass transportation. However, the amount of oil consumed by transportation is higher than by the power plant subsystem.

In addition to quantifying emissions, a key aspect of this work was to evaluate the energy flows within the system boundaries to assess the net energy produced. The net energy production of the system was found to be highly positive. One unit of fossil fuel energy is required to produce 15.6 units of biomass-generated electricity. The worst case tested in the sensitivity analyses gave a ratio of no less than 11. Additionally, the life cycle efficiency (34.9%), which includes all energy consumed within the system, is not substantially less than the power plant efficiency (37.2%). Not including power plant parasitic losses, feedstock production accounts for 77% of the total system energy consumption.

Transporting the biomass to the power plant required fewer resources and less energy than both feedstock production and power plant operations. Additionally, air and water emissions are lowest from this subsystem. Changing the mode and/or emissions of transportation will not greatly affect the overall impact of this system on the environment.

Apart from the impact soil carbon sequestration has on the carbon closure, biomass yield was found to have the largest effect on the amount of resource consumption, net emissions, and energy use for the system. Changing the amount of fossil fuel used at the plantation and changing the power plant efficiency also had noticeable effects. Most importantly, however, the conclusions drawn remain the same for all sensitivity cases studied. That is, carbon closure and life cycle efficiency are very high for this system. Additionally, the fossil fuel energy ratio does not decrease substantially, indicating that the electric energy the system produces will always be far more than the fossil fuel energy it consumes.

10.0 Future Work

To complement this work, we will extend the life cycle study of biomass processes and expand the developed methodology to other systems. The next set of studies will seek to answer the question of how this process measures up environmentally against fossil-based systems. Life cycle assessments will be performed on three coal-fired power plants, one which incorporates new emissions control technologies, one which meets the New Source Performance Standards, and one which represents a plant in operation today. Another power generation option that is likely to be examined is co-firing of biomass in coal- or oil-fired boilers. This option of retrofitting existing power plants will likely be the first step for utilizing biomass in commercial, large-scale electricity systems. Finally, an assessment of a natural gas-fired IGCC plant may be conducted.

A system similar to that studied in this analysis but which uses other biomass feedstocks may also be examined. An herbaceous feedstock such as switchgrass, a feed from which co-products can be generated, such as alfalfa, and agricultural and forest waste wood are examples.

An interesting extension of this study would be the incorporation of biomass-derived diesel fuels into farming operations. Theoretically, this would close the carbon balance further, although the emissions related to growing biomass would be increased. Additionally, it would be useful to study the environmental effects of biomass crops compared to traditional agriculture crops.

11.0 Related Studies

A brief summary of some of the previous studies that relate to this work is given in this section. Data from many of these studies were used in this assessment, and referenced elsewhere in the text. Although this list is not all-inclusive, it serves to illustrate the nature of past efforts.